Session IV

System Software Technology

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Research Concepts

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Scope

iWarp can be used in three different scenarios:

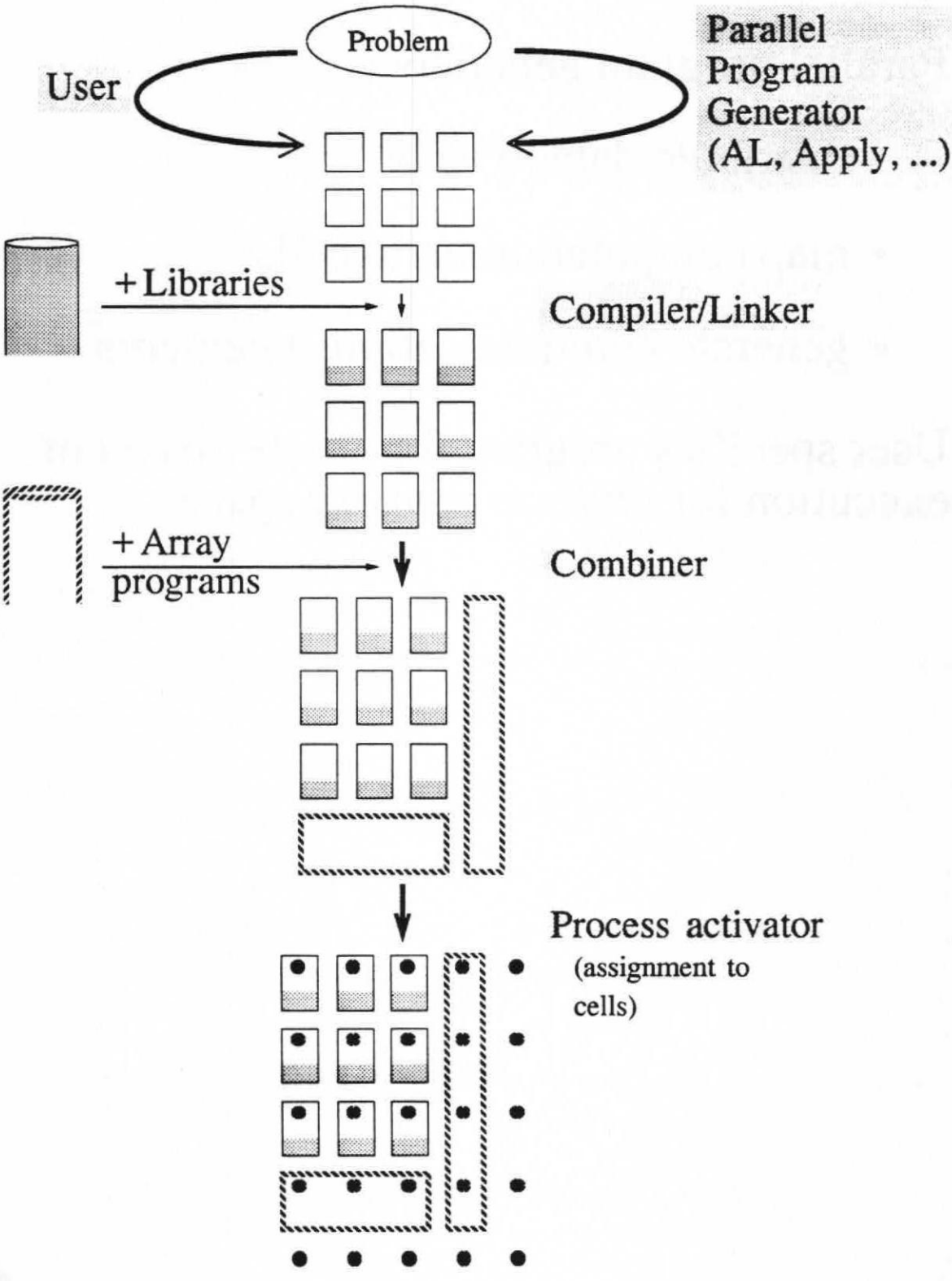
- Large Arrays
  (32+ cells)
- Single-board arrays
  (SBAs) (1-32 cells)
- Application-specific arrays
  (No system software support)

How is iWarp programmed?

Two approaches:

- Parallel program generators
  - Apply
  - AL
- Conventional methods
  - Familiar languages
  - Cell to cell communication operations

How is iWarp programmed?



Parallel program generators

Parallel program generators

- distribute data to cells
- map computation on to cells
- generate communication statements

User specifies program for *single thread* of execution for *uniform memory* space

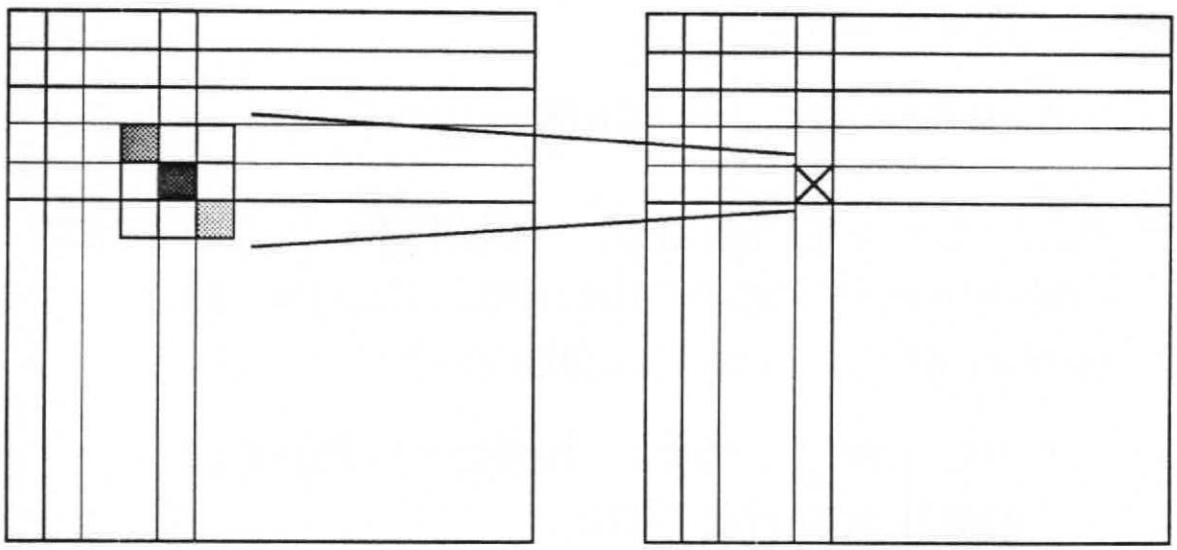
Parallel program generators

Parallel Program generators developed at Carnegie Mellon

- Apply: special-purpose language for image processing
  - deals with borders, image expansion, reduction
  - in use for 3+ years
- AL: array language prototype for domain decomposition problems, (matrix and linear algebra applications)
  - use programmer hints on how to partition the data
  - Automatic mapping of computation
  - in use for 1+ years

Apply

outI := inI(-1,1)+inI(0,0)+inI(1,-1)/3



Input (inI)

Output (outI)

Apply

Apply has been used for low-level vision algorithms such as:

- Color conversion
- Contrast Enhancement
- Edge detection
- Image addition, subtraction, multiplication
- Point operators
- Thresholding

AL

AL compiler maps computation and data onto multiple cells

Key concepts:

- Distributed arrays (**`DARRAY`**)
  - User directive that array *can* be distributed
  - User controls *how* data is distributed
- Normal variables
  - Cannot be distributed
  - Duplicated on all cells
- Partition **`DO`** loops

AL

- Data relations
  - Window relation: array elements must be grouped together
  - Cross relation: different arrays must be grouped together

AL - Example

```
Matrix_Mult(A, B, C, N)
DARRAY float A[][], B[][],
                C[][];
int i, j, k, N;
float Brow[];
XREL ((A,1) (C,1)

do (k=0, n)
ALIGN* (j=0, n)
    Brow[j] = b[k][j];
DO* (i=0, n)
 DO (j=0, n)
 C[i][j] = C[i][j] +
        A[i][j]*Brow[j];
```

Compiler technology

- Developed optimizing compiler for Warp
  - Software pipelining: effective code scheduling technique
- Used compiler in micro-architecture tradeoff studies

Software pipelining

```
FOR (I=0; I<N, I++)
  A[I]=B[I]*C;
```

```
      load C -> R0
      load #0 -> R1
      branch L1
L0:   load B[R1] -> R2
      mul R2, R0 -> R3
      store R3 -> A[R1]
      add #1, R1 -> R1
L1:   bra_cond (R1<N) L0
```

```
load C -> R0
load #0 -> R11
load #0 -> R1
load B[R1++] -> R2
mul R2, R0 -> R3        load B[R1++] -> R2
loop (N-2)
store R3 -> A[R11++]  mul R2, R0 -> R3      load B[R1++] -> R2
                      store R3 -> A[R11++]  mul R2, R0 -> R3
                                            store R3 -> A[R11++]
```

Combiner

Allows the programmer to build an array application

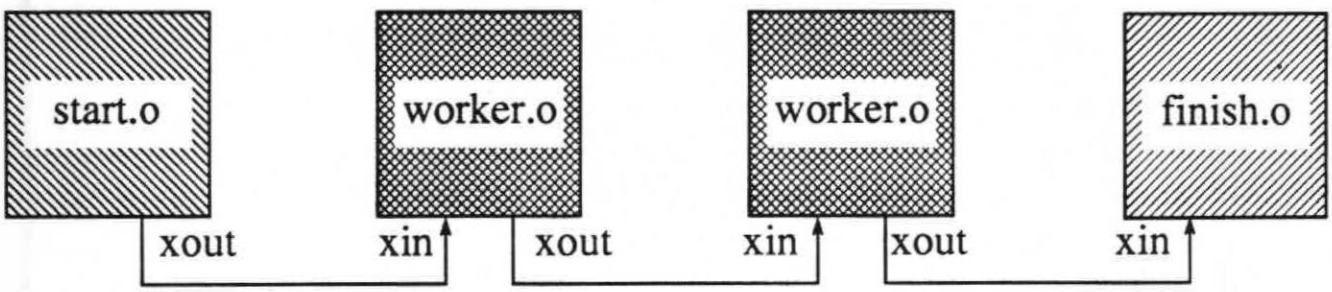
- Creates "array module"
- Homogeneous array programs
- Heterogeneous array programs

Invoked automatically by parallel program generators

Combiner Example

```
for (i=0; i<NUM, i++)
 connect_port(
    Cell[0,i].xout,
    Cell[0,i+1].xin)

Activate(
     Cell[0,0], start.o)
for (i=1, i<NUM, i++)
 Activate(
     Cell[0,i], worker.o)
Activate(Cell[0,NUM],
          finish.o)
```



Execution environment

Host:

Provides external access to the iWarp array

- Workstation
- File server
- Special I/O systems (bulk memory)
- Sensors

Host resident:

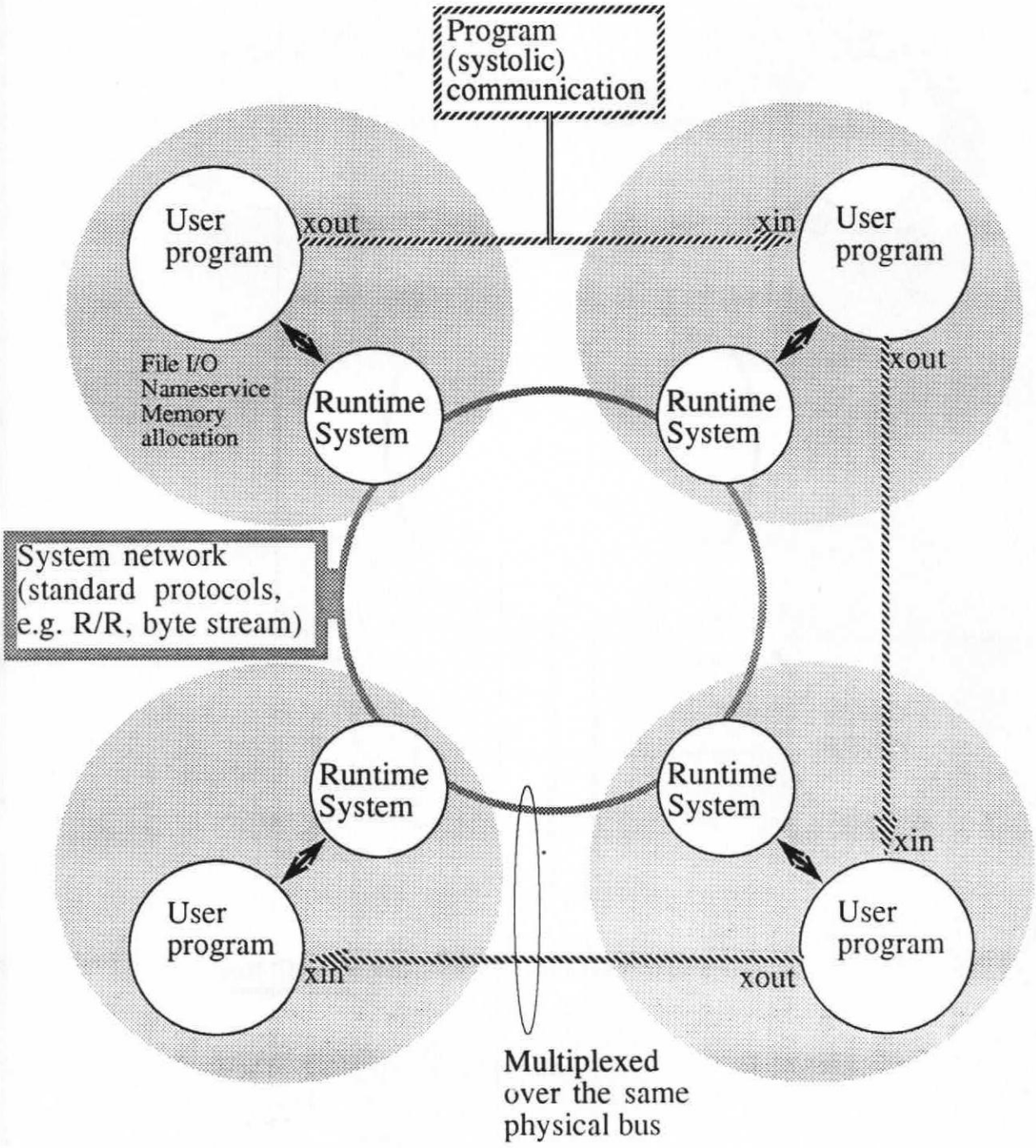
- Array monitor: grants access, supplies data and code, retrieves data, and terminates execution

Execution environment (continued)

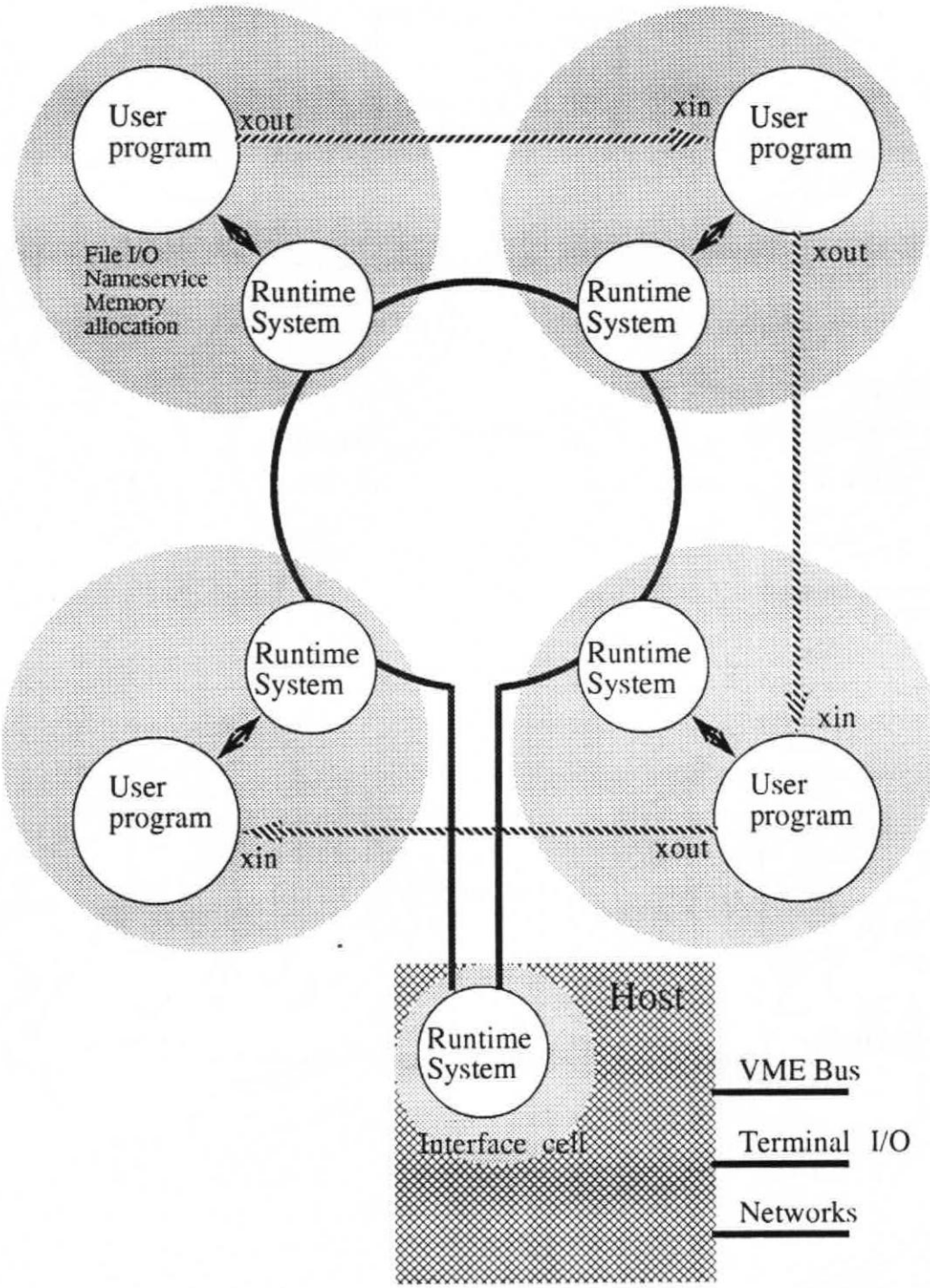
Cell resident:

- Runtime system:
  - down/up loads code and data
  - starts/stops execution
  - interfaces to debugger
  - resource management
  - system network communication

Cell runtime system



Host interaction



Session IV

System Software Technology

Delivered Capability

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Presentation Overview

- Basic software: outline
  - Single cell issues
  - Array issues
- Program execution: outline
- Basic software: details
- Program runtime system: details
- Summary
- Questions & answers

Program Development Environment

Contains the software building blocks to develop application programs for iWarp systems

Uses operating system of development platform to supply:

- editors
- version control
- window management

Identical software environment for single board array or processor array

Program development software executable on any node in the LAN

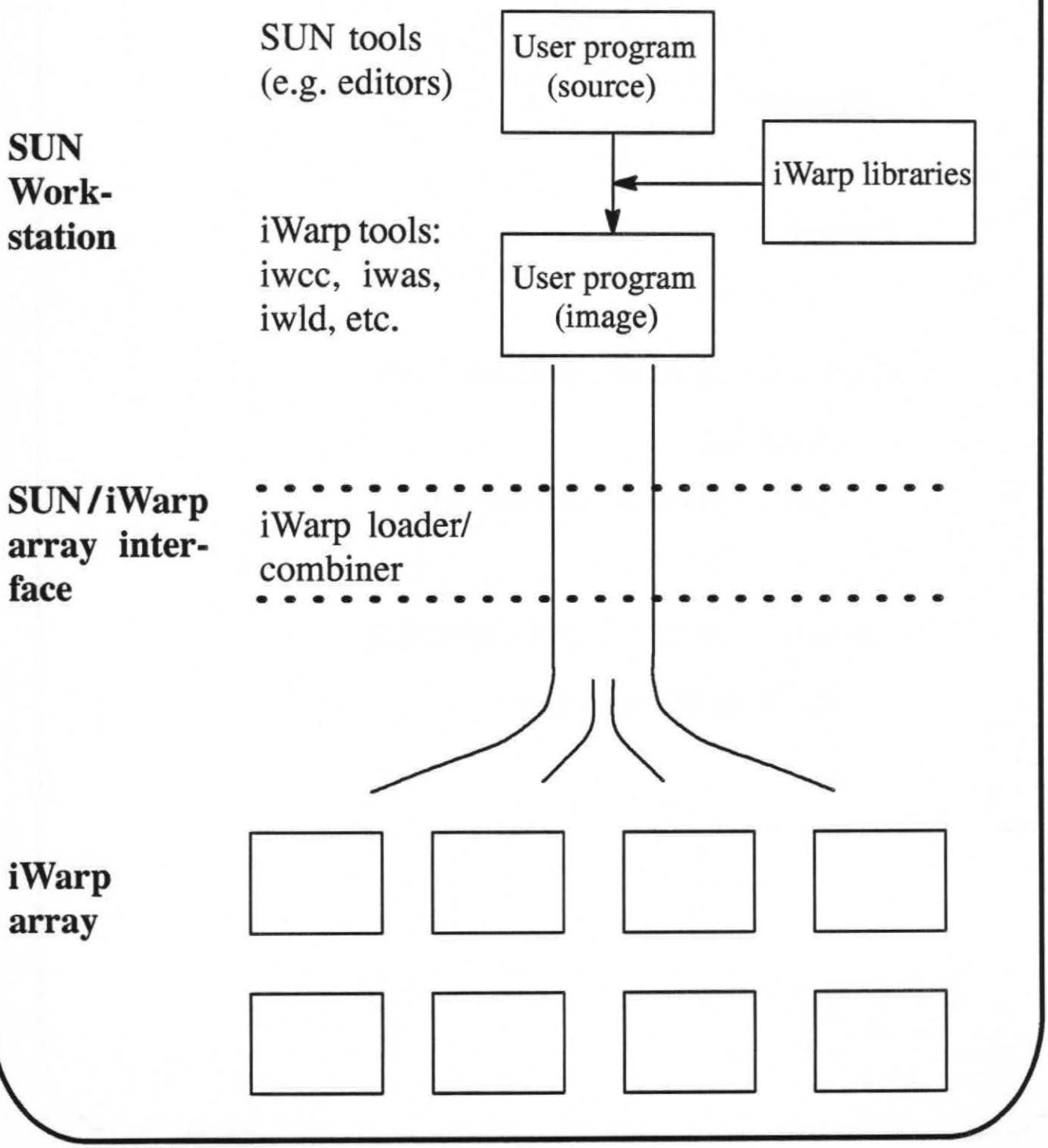
iWarp Single–Cell Program Development Tools

- **C Optimizing Compiler**
  - standard Kernighan & Ritchie C
  - software pipelining (long instruction word optimizations)
  - direct access to system level communication primitives (send & receive); h/w conditions
  - assembly code inlining facility
- **FORTRAN Optimizing Compiler**
  - standard ANSI 77 FORTRAN
  - VAX/VMS extensions
  - direct access to system level communication primitives (send & receive); h/w conditions
  - Inlining of compiled C functions in FORTRAN programs
  - Shared back–end with C compiler
- **Common Calling Conventions**

iWarp Single–Cell Program Development Tools

- **Assembler**
- **Linker**
- **Object Code Manipulation Tools**
  - librarian
  - object code cross reference
- **Symbolic Source Level Debugger**
  - built-in disassembler

Program Development Environment



Program Development Environment

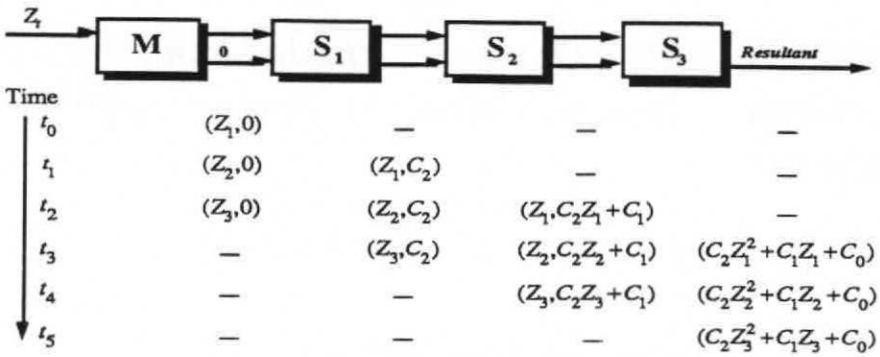
Standard direct file I/O between the host and the iWarp array permit simple and straight forward application development.

Steps in developing an application.

- Write and debug the application on the host (using the host I/O).
- Move the application to a single cell array (using the host I/O).
- Distribute the application across multiple cells to test and debug communication.
- Tailor the I/O to the application, removing or modifying host file I/O as desired.

Program Development Environment

$$p(z) = c_n z^n + \ldots + c_1 z + c_0$$




```
for ( i = 0; i < nz; i++ ) {
  _sendf( GATE0, z[i] );
  _sendf( GATE1, fzero );
}
```

```
for ( i = 0; i < nz; i++ ) {
  xin = _receivef( GATE0 );
  yin = _receivef( GATE1 );
  _sendf( GATE0, xin );
  _sendf( GATE1, coeff + yin * xin );
}
```

```
for ( i = 0; i < nz; i++ ) {
  ftmp = _receivef( GATE0 );
  p[i] = _receivef( GATE1 );
}
```

- Input initial values of coefficients and solution points (z) from host using **scanf**.
- Using systolic communication provided through the **send** and **receive** intrinsic functions, the terms of the polynimial are accumulated.
- Final values of **p** are collected and sent to host using **printf**.

Program Development Environment

```
#include <stdio.h>

asm float fast_dp(addrp,addrq,cnt)
{
% register addrp,addrq; tmpreg cnt,t1,t2,t3,t4; tmpreg return;
   movereg.w addrp,t1
   movereg.w addrq,t2
   sub 2,cnt
   {                                          ld.w (t1,4),lm2;    ld.w (t2,4)+=,lm0}
   {                                          ld.w (t1,4)+=,lm2; ld.w (t2,4)+=,lm0}
   {                    fmul.f lm0,lm2,t3;    ld.w (t1,4)+=,lm2; ld.w (t2,4)+=,lm0}

loop cnt

el{
    fadd.f t4,t3,t4;    fmul.f lm0,lm2,t3;    ld.w (t1,4)+=,lm2; ld.w (t2,4)+=,lm0
   }
   {fadd.f t4,t3,t4;    fmul.f lm0,lm2,t3;    ld.w (t1,4)+=,lm2}
   {fadd.f t4,t3,t4;    fmul.f lm0,lm2,t3}
   {fadd.f t4,t3,return}
}

main()
{
  register float *p = &a[0];
  register float *q = &b[0];
  register int vec_len;
  register float s = 0.0;
  register int i;

/*  for(i=0;i<vec_len;i++){
 *    s = s + a[i]*b[i];
 *  }
 */

  s = fast_dp(p,q,vec_len);

}
```

The assembly language inlining feature provides a powerful method of including specific assembly language segments into ordinary C code. Parameters to the pseudo–function are associated with registers allocated by the compiler to provide a very efficient and flexible interface to the assembly sequence. Here a single C&A instruction is used to perform a dot–product. The software–pipelining optimization phase of the C compiler will eventually provide similarly efficient code from appropriate C code.

Application Program Development Tools

Apply

- an image processing language
- callable by standard C and FORTRAN
- WEB library with over 100 routines
- generates C source code

Apply is the first step in parallel program generators for iWarp

Program Runtime Environment

iWarp Runtime System (host-resident)

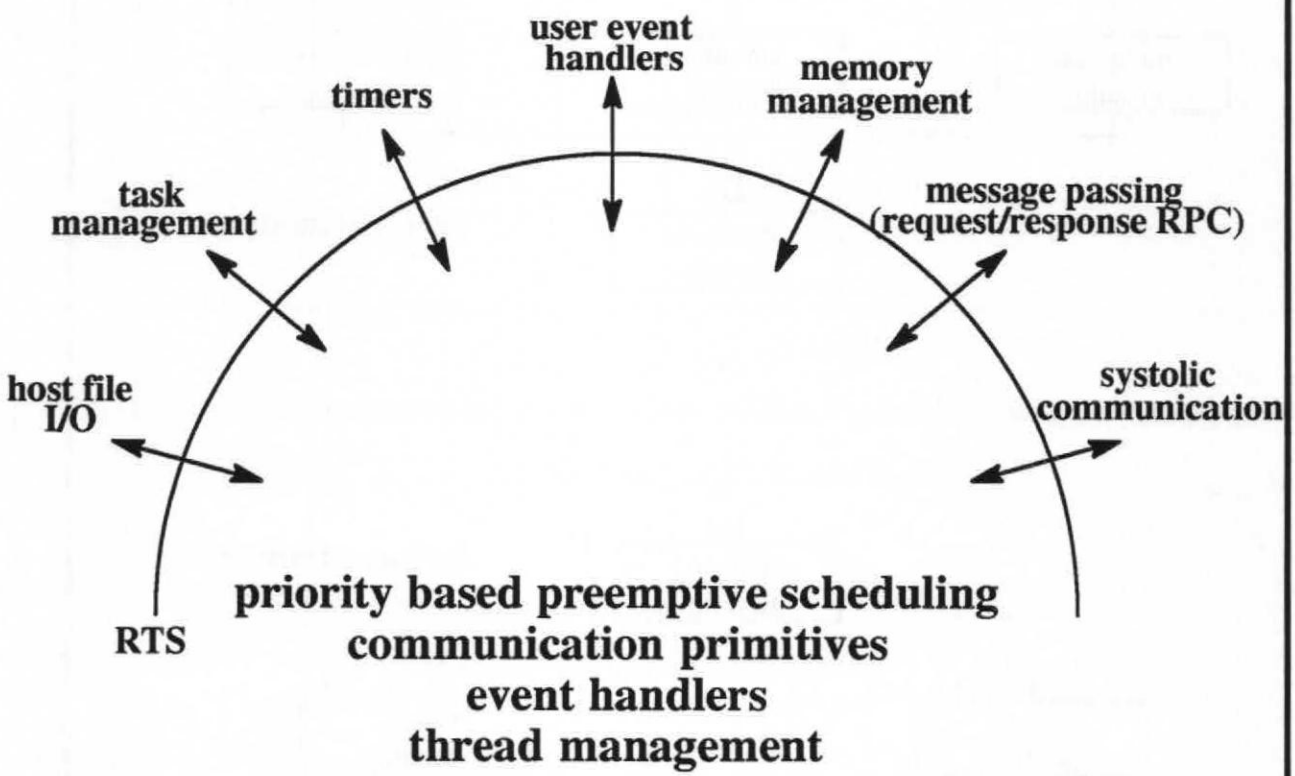
- **Combiner**
  - joins multiple cell programs into a single array load module
- **Array Allocation**
  - grants access to iWarp hardware
  - queues jobs awaiting execution
- **Array Job Management**
  - job activation/kill
  - obtain job state information
  - multi-cell debugger

Program Runtime Environment

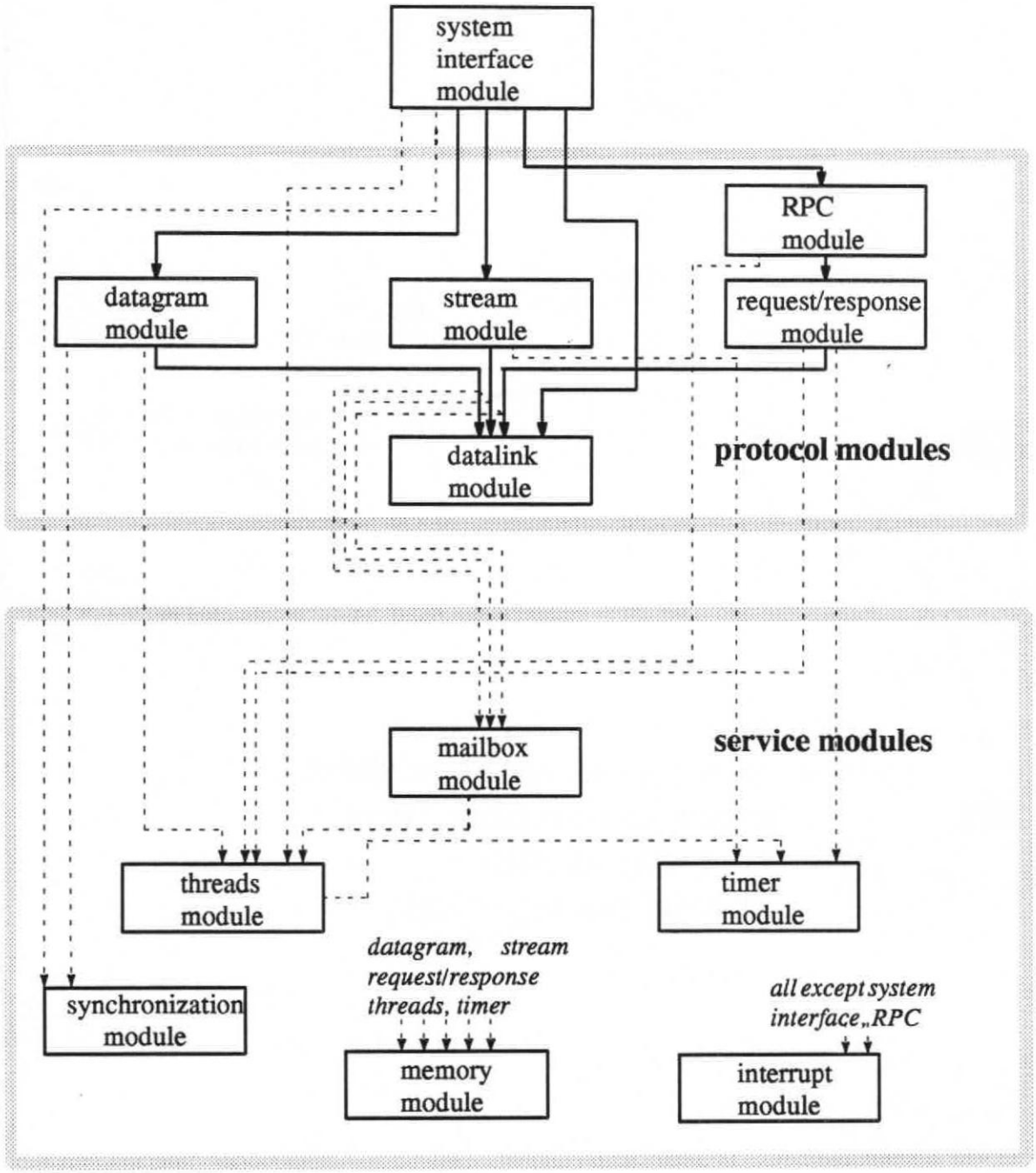
iWarp Runtime System (cell-resident)

- **Basic Runtime Kernel**
  - interrupt handlers
  - thread management
  - resource management
- **Process Activator**
  - loads user data and code
  - starts application program execution on cell
- **User-programmed Communication**
  - memory–to–memory message passing
  - systolic communication
- **Standard Libraries**
  - UNIX System V standard I/O
  - iPSC compatibility library
  - math intrinsic function library

Program Runtime Environment



iWarp Runtime System



Summary

- **Complete set of program development tools**
  - Optimizing compilers
  - Parallel program generators
  - Debugger
- **Runtime environment for efficient execution**
  - Systolic communication
  - Well-known message-based protocol types (request/response, RPC)
- **Base for effective problem partitioning**
  - Large arrays (1+ GFLOPS)
  - Single-board arrays